(12) **EUROPEAN PATENT APPLICATION**

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(54) **Single crystal conical portion growth control method and apparatus.**

(57) A conical portion growth control method and an apparatus used in the method grow a conical portion 32B of a single crystal rod 32 by pulling the crystal rod from a melt 16 heated by a heater 14 in the Czochralski method, and aim to enhance reproducibility of the shape of the conical portion 32B and shorten the conical portion 32B. The control method has the steps of presetting a target value pattern 66 of the temperature of a concave portion 46 formed on a heat-insulating material 18 and a target value pattern 64 of the diameter change rate of a growing portion of the crystal rod, measuring the diameter of the crystal growing portion, calculating the change rate of the diameter, measuring the temperature of the concave portion, correcting the target temperature based on a difference between the calculated value and the target value of the diameter change rate, and controlling the amount of electricity supplied to the heater so that the measured temperature becomes equal to the corrected target temperature.

EP 0 482 438 A1

Robert H. Fuerhoff et al.
Serial No. 09/502,340
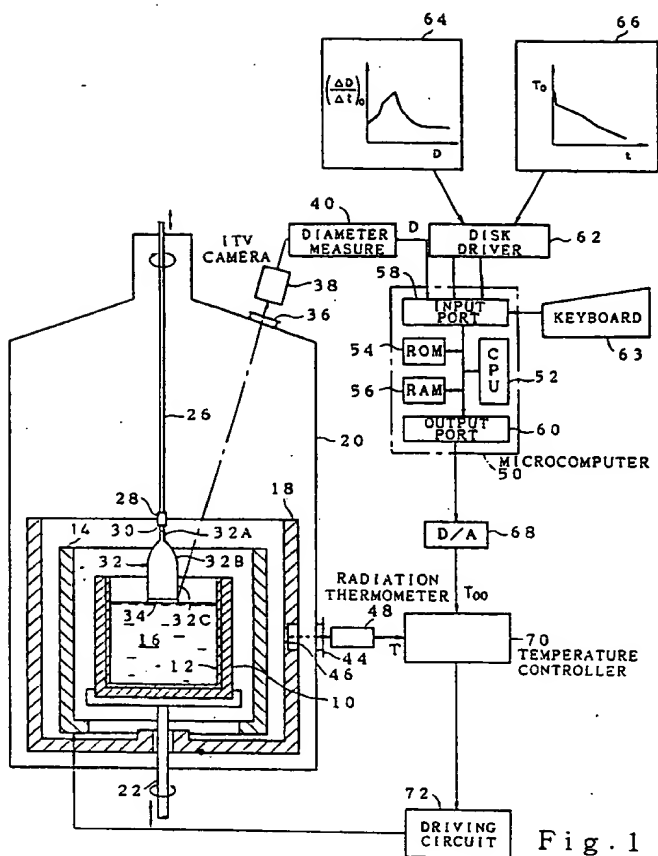Filed 02/10/2000
Our File MEMC-99-0900 (2632)
Ref. No. 9

Fig. 1

BACKGROUND OF THE INVENTION

Field of the Invention

5   The present invention relates to a conical portion growth control method which grows a conical portion of a single crystal rod by pulling up the crystal rod from a melt by using the Czochralski method and to an apparatus for use in the control method.

Description of the Related Art

10   In this kind of conical portion growth control method, a single crystal is grown by soaking a seed crystal having a diameter of approximately 10mm in a melt and pulling up the seed crystal from the melt. In other words, after dislocations are eliminated by shortening the growing diameter of the seed crystal to approximately 3mm, the diameter of the crystal is increased so as to grow a desired cylindrical body
15   portion.

Since the diameter increasing portion (conical portion) of the crystal is not used as a product, it is necessary to make the length as small as possible so as to reduce costs of producing the single crystal. However, if the conical portion is too short, that is, if the crystal diameter is rapidly increased, the atoms of the crystal are disarranged and the body portion cannot be grown as single crystal.

20   The crystal diameter is increased by lowering the temperature related to the melt or by reducing the crystal pull-up speed. Although response in the crystal diameter to the change in the crystal pull-up speed is even prompter than response in the crystal diameter to the change in the temperature related to the melt, the atoms of the crystal are likely to be disarranged in the case where the change in the crystal pull-up speed is used to control the diameter. On the other hand, if a desired shape of the conical portion is set,
25   the crystal diameter is measured and electricity to be supplied to a heater for heating the melt is controlled so as to obtain the desired shape, a large amount of hunting occurs and thus the surface of the crystal is made uneven. It is necessary to prevent the atoms of the crystal from being disarranged by making the slope of the desired shape gentler than a slope ideal for making the conical portion as short as possible. In short, the conical portion is longer than necessary.

30   Conventionally, a target temperature pattern in which the temperature of a melt falls with the passage of time is set, and the amount of electricity supplied to a heater for heating the melt is controlled so that the temperature related to the melt reaches the desired temperature. Since the amount of hunting is small in this control method, the surface of the crystal is not so uneven.

However, since the shape of the conical portion also depends upon the diameter of a narrow portion of
35   the crystal, a target diameter of the body portion, the crystal pull-up speed, the rotation speed of a pulling shaft, the rotation speed of a crucible, the vertical position of the crucible with respect to the heater, the inner diameter of the crucible, the amount of a melt in the crucible and so on, it is difficult to obtain the shape of a conical portion having high reproducibility. Therefore, in order to prevent the disarranging of the atoms of the crystal, it is necessary to make the slope of a target temperature pattern with respect to the
40   elapsed time gentler than an ideal slope of the temperature pattern for making the conical portion as short as possible. As a result, the conical portion is longer than necessary.

SUMMARY OF THE INVENTION

45   An object of the present invention is to provide a conical portion growth control method capable of shortening a conical portion while enhancing the reproducibility of the shape of the conical portion, and an apparatus for use in the method.

A conical portion growth control method of the present invention which grows a conical portion of a single crystal rod by pulling the crystal rod from a melt heated by a heater in the Czochralski method
50   comprises the steps of presetting a target value (T_0 or $T_0 + \Delta T_0$) of the temperature related to the melt and a target value of the diameter change rate of a growing portion of the crystal rod, measuring the diameter of the crystal growing portion, calculating the change rate of the diameter, measuring the temperature related to the melt, correcting the target temperature based on a difference between the calculated value and the target value of the diameter change rate, and controlling the amount of electricity supplied to the heater so
55   that the measured temperature becomes equal to the corrected target temperature.

A conical portion growth control apparatus of the present invention which grows a conical portion of a single crystal rod by pulling the crystal rod from a melt heated by a heater in the Czochralski method comprises a means for measuring the diameter of a growing portion of the crystal rod, a means for

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calculating the change rate of the diameter, a first setting means in which a target value of the change rate of the diameter is set, a means for measuring the temperature related to the melt, a second setting means in which a target value of the temperature related to the melt is set, a target temperature correction means for correcting the target temperature based on a difference between the calculated value and the target value of the diameter change rate, and a heater electricity control means for controlling the amount of electricity supplied to the heater so that the measured temperature becomes equal to the corrected target temperature.

In the above method and apparatus of the present invention, although the target values of the temperature and the diameter change rate each are set as a function of time, the pull-up length or the diameter, it is most preferable to set a target value of the diameter change rate as a function of the diameter in order to improve the reproducibility of the shape of the conical portion. This improvement in reproducibility then makes it sufficient for a function of time, which is the simplest of the above functions, to be set as a target value of the temperature.

The above temperature is, for example, the temperature of a concave portion formed on a heat insulating material which surrounds the heater, or the surface temperature of the melt.

The correction of the target temperature is preferably carried out by adding the total value of a proportional component, a differential component and an integral component concerning the difference between the calculated value and the target value of the diameter change rate to the target temperature.

Furthermore, the amount of electricity is controlled by, for example, performing a PID action with respect to the difference between the measured temperature and the corrected target temperature.

In the present invention, since the crystal diameter is not directly controlled, a control operation is performed so that the temperature related to the melt becomes equal to a target temperature T_0 and the target temperature T_0 is corrected based on a difference between the diameter change rate $\Delta D/\Delta t$ and a target diameter change rate $(\Delta D/\Delta t)_0$ instead of the diameter itself, it is possible to improve the reproducibility of the shape of a conical portion, and thus to make the conical portion shorter than the conventional one without disarranging the atoms of the crystal.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 to 5 each show an embodiment of conical portion growth control method and apparatus according to the present invention.

Fig. 1 is a schematic view showing the construction of a crystal growing apparatus to which the conical portion growth control apparatus is applied;

Fig. 2 is a flow chart showing the procedures of a microcomputer 50 shown in Fig. 1; and

Figs. 3 to 5 are diagrams showing the results of the actual use of the embodiment of the conical portion growth control apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of the present invention will now be described with reference to the accompanying drawings.

Fig. 1 shows a crystal growing apparatus using the Czochralski method to which a conical portion growth control apparatus is applied.

A mass of polysilicon crystal, contained in a quartz crucible 12 fitted into a graphite crucible 10, is heated and melted into a melt 16 by supplying electricity to a heater 14 which surrounds the graphite crucible 10. The heater 14 is surrounded by a graphite heat-insulating material 18. These components 10 to 18 are housed in a chamber 20 where the gas is emptied to a vacuum.

The graphite crucible 10 is rotated and elevated in the directions of the arrows by an unillustrated motor through a crucible rotating shaft 22 which is concentric with the graphite crucible 10. On the other hand, a seed crystal 30 is retained through a holder 28 at the bottom of a pulling shaft 26, which is concentric with the graphite crucible 10, above the graphite crucible 10.

A single crystal 32 is grown by soaking the lower end of the seed crystal 30 in the melt 16, and pulling up and rotating the lower end in the directions of the arrows. A narrow portion 32A for freeing the crystal from dislocations, a conical portion 32B for increasing the diameter of the crystal to a target diameter D_B and a body portion 32C having the target diameter D_B of the single crystal 32 are grown in this order.

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A window 36 is formed on a shoulder portion of the chamber 20 to image a luminous ring 34 formed along an interface between the single crystal 32 and the melt 16 therethrough, and an imaging device 38 is fixed to the chamber 20 opposite to the window 36. A composite image signal output from the imaging device 38 is supplied to a diameter measurement device 40 which measures the diameter of the luminous ring 34 by image processing.

On the other hand, a window 44 is formed on a side of the chamber 20 to measure the temperature related to the melt 16 therethrough, a concave portion 46 is formed on a side of the heat-insulating member 18, and a radiation thermometer 48 is fixed to the chamber 20 opposite to the concave portion 46 through the window 44.

A target value T_0 of the temperature T detected by the radiation thermometer 48 is determined by a microcomputer 50.

As is well known, the microcomputer 50 is composed of a CPU 52, a ROM 54, a RAM 56, an input port 58 and an output port 60. The diameter D is output from the diameter measurement device 40 to the input port 58. Furthermore, for example, if the control mode is switched to the automatic control mode after growing the narrow portion 32A in the manual control mode, a conical portion growth start signal is supplied to the input port 58. The input port 58 is connected to a magnetic disk driver 62 and a keyboard 63. A target diameter change rate file 64 and a target temperature file 66 are read into the microcomputer 50 through the magnetic disk driver 62, and stored in the RAM 56. The target diameter change rate file 64 is, as shown in Fig. 1, a data file which expresses a target value $(\Delta D/\Delta t)_0$ of the change rate of the crystal diameter D with respect to the time t as a function of the diameter D. Furthermore, the target temperature file 66 is, as shown in Fig. 1, a data file which expresses a target value T_0 of the temperature of the concave portion 46 as a function of the time t.

The CPU 52 reads an initial correction value ΔT_0, described below, from the keyboard 63 through the input port 58 according to a program stored in the ROM 54, reads the diameter D from the diameter measurement device 40 through the input port 58, calculates a corrected target temperature T_{00} with reference to the target diameter change rate file 64 and the target temperature file 66 stored in the RAM 56, and supplies the target temperature T_{00} to a temperature controller 70 through the output port 60 and a D/A converter 68.

The temperature controller 70 supplies electricity to the heater 14 through a driving circuit 72 so that T becomes equal to the target temperature T_{00} by, for example, a PID action.

The process of the microcomputer 50 will now be described with reference to Fig. 2.

(98) A crystal diameter D and the pull-up speed at the end of the narrow portion are compared with respective standard values, the initial correction value ΔT_0 of a target temperature T_0 is calculated based on differences between the values and input to the microcomputer 50 by operating the keyboard 63.

(100) The diameter D is read from the diameter measurement device 40 the number k of times in every fixed period $\Delta\tau$, and an average value D_i of the read diameters D is calculated.

(102) It is checked whether or not the diameter D_i reaches a set value D_A. In the case where $D_i < D_A$, since the target value of the diameter change rate is set at a relatively small value in order to prevent the disarranging of the atoms of the single crystal 32, it seems that there is not so much necessity of correcting the target temperature T_0.

(104) If $D_i < D_A$, a target temperature T_0 at the time $t = i\Delta t$ is read from the target temperature file 66 stored in the RAM 56, and a corrected target temperature T_{00} is calculated from $T_0 + \Delta T_0$. Δt is $k\Delta\tau$, and an initial value of i is 1.

If $D_i \geqq D_A$,

(106) It is checked whether or not the diameter D_i reaches a target diameter D_B of the body portion 32C.

(108) If $D_i < D_B$, a change rate $\Delta D/\Delta t$ of the diameter D_i with respect to time is calculated. AD is $(D_i - D_{i-m})/m$.

(110) A target diameter change rate $(\Delta D/\Delta t)_0$ and a target temperature T_0 at the time $t = i\Delta t$ are read from the target change rate file 64 and the target temperature file 66 stored in the RAM 56, respectively.

(112) $d_i = \Delta D/\Delta t - (\Delta D/\Delta t)_0 \cdot (1)$ is calculated.

(114) A correction value S of the target temperature T_0 to improve reproducibility of the shape of the conical portion 32B without making the conical portion 32B unevener is calculated. For example, it is assumed that the correction value S is obtained by adding a proportional component, a differential component and an integral component with respect to the above d_i. In this case,

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$$S = K_P d_i + K_I \sum_{j=1}^{i} d_j \Delta t + K_D \Delta d / \Delta t.$$

K_P, K_I and K_D are constants empirically selected so as to perform the correction most effectively, and $\Delta d = d_i - d_{i-1}$.

(116) T_{00} is calculated from $T_0 + \Delta T_0 + S$.

(118) The corrected target temperature T_{00} is supplied to the temperature controller 70 through the D/A converter 68. The number of i is increased and the step 100 is repeated.

Figs. 3 to 5 show changes of the diameter D, the diameter change rate $\Delta D / \Delta t$, the target diameter change rate $(\Delta D / \Delta t)_0$, the target temperature T_0 and the rotation speed CR of the quartz crucible 12 with respect to the time t (the automatic conical portion growth control is started when t = 0) when the conical portion 32B is actually grown by using the apparatus in this embodiment. Test conditions when the conical portion 32B is grown are as follows:

Quartz crucible 12: vertical position fixed

Pulling shaft 26 : pull-up speed fixed

Temperature controller 70: PID controller

$\Delta \tau$ = 6 seconds, Δt = 1 minute, m = 2

D_A: 80mm

D_B: 158mm

Since hunting of the target temperature T_{00} occurs when $m\Delta t$ is too short and the correction is not precise when $m\Delta t$ is too long, it is important to select $m\Delta t$. A preferable range of $m\Delta t$ is 1 to 3 minutes.

Referring to Figs. 3 to 5, the dial value is in linear relation to the temperature. T_0 rapidly falls when t < 2 minutes in order to increase the conical portion growing speed. $T_0 + \Delta T_0 < T_{00}$ when t < 2 minutes for the following reason. In other words, the driving circuit 72 rotates the dial by the motor so as to control the amount of electricity to be supplied to the heater 14, and if the change rate of the target temperature is too large, the rotation speed of the motor reaches the upper limit and becomes late in catching up with the change.

Referring to Fig. 3, a deviation d of the diameter change rate with respect to the target value is relatively small when $D \geq D_A$. At the time T = 60~65 minutes, the target temperature T_0 is corrected upward.

Referring to Fig. 4, d is relatively large at the time t = 45~50 minutes, and the target temperature T_0 is corrected upward. When t > 50, the integral constant remains as a correction value, and the slopes of T_0 and T_{00} are equal to each other.

Referring to Fig. 5, since d becomes a negative value at the time t > 40, the target temperature T_0 is corrected downward.

The case in which conical portions 32B of 40 single crystal rods are grown in the conventional method without correcting the target temperature T_0 and the case in which conical portions 32B of 40 single crystal rods are grown in this method which corrects the target temperature T_0 are compared with each other. The result of the comparison is as follows:

Average length of conical portion

conventional method: 10.7cm   this method: 10.1cm Average deviation of length of conical portion

conventional method: 1.49   this method: 0.65

Proportion of defective (number of rods with dislocation/40)

conventional method:0.45   this method: 0.10

The defective means a rod which is lowered, melted in the melt and pulled up again due to dislocation.

It seems that the proportion of the defective is high in the conventional method because the actual diameter change rate $\Delta D / \Delta t$ becomes partially too large since the conical portion is shortened, the target diameter change rate $(\Delta D / \Delta t)_0$ is relatively large, and reproducibility of the surface shape is low, thereby causing dislocation. On such strict conditions, the reproducibility of the surface shape is enhanced and the proportion of defectives is greatly lowered by automatically correcting the temperature as described in this embodiment.

Claims

1. A conical portion growth control method which grows a conical portion (32B) of a single crystal rod (32) by pulling said crystal rod from a melt (16) heated by a heater (14) in the Czochralski method, comprising the steps of:

   presetting a target value (66) of the temperature related to said melt and a target value (64) of the diameter change rate of a growing portion of said crystal rod;

   measuring the diameter of said crystal growing portion (100);

   calculating the change rate of the diameter (108);

   measuring the temperature related to said melt;

   correcting said target temperature based on a difference between said calculated value and said target value of the diameter change rate (112~116); and

   controlling the amount of electricity supplied to said heater so that said measured temperature becomes equal to said corrected target temperature.

2. A control method according to claim 1, wherein said target value (66) of the temperature is a function of time, and said target value (64) of the diameter change rate is a function of the diameter.

3. A control method according to claim 1, wherein said temperature related to said melt is the temperature of a concave portion (46) formed on a heat-insulating material (18) surrounding said heater (14).

4. A control method according to claim 2, wherein the correction of said target temperature is performed by adding the total value of a proportional component, a differential component and an integral component related to the difference between said calculated value and said target value of the diameter change rate to said target temperature.

5. A control method according to claim 4, wherein the amount of said the electricity is controlled by performing a PID action with respect to the difference between said measured temperature and said corrected target temperature.

6. A conical portion growth control apparatus which grows a conical portion (32B) of a single crystal rod (32) by pulling up said crystal rod from a melt (16) heated by a heater (14) in the Czochralski method, comprising:

   means (38, 40) for measuring the diameter of a growing portion of said crystal rod;

   means (50, 108) for calculating the change rate of the diameter;

   first setting means (64) in which a target value of the change rate of the diameter is set;

   means (48) for measuring the temperature related to said melt;

   second setting means (66) in which a target value of the temperature related to said melt is set;

   target temperature correction means (50, 112~116) for correcting said target temperature based on a difference between said calculated value and said target value of the diameter change rate; and

   heater electricity control means (70, 72) for controlling the amount of electricity supplied to said heater so that said measured temperature becomes equal to said corrected target temperature.

7. A control apparatus according to claim 6, wherein said target value (64) of the diameter change rate set in said first setting means is a function of the diameter, and said target value (66) of the temperature set in said second setting means is a function of time.

8. A control apparatus according to claim 6, wherein said temperature measurement means (48) detects the temperature of a concave portion (46) formed on a heat-insulating material (18) surrounding said heater (14).

9. A control apparatus according to claim 7, wherein said target temperature correction means (50, 112~116) adds the total value of a proportional component, a differential component and an integral component related to the difference between said calculated value and said target value of the diameter change rate to said target temperature.

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10. A control apparatus according to claim 9, wherein said heater electricity control means (70, 72) is a controller for performing a PID action with respect to the difference between said measured temperature and said corrected target temperature.

5   11. A control apparatus according to claim 7, wherein said diameter change rate calculating means calculates the change rate of said measured diameter with respect to one to three minutes.
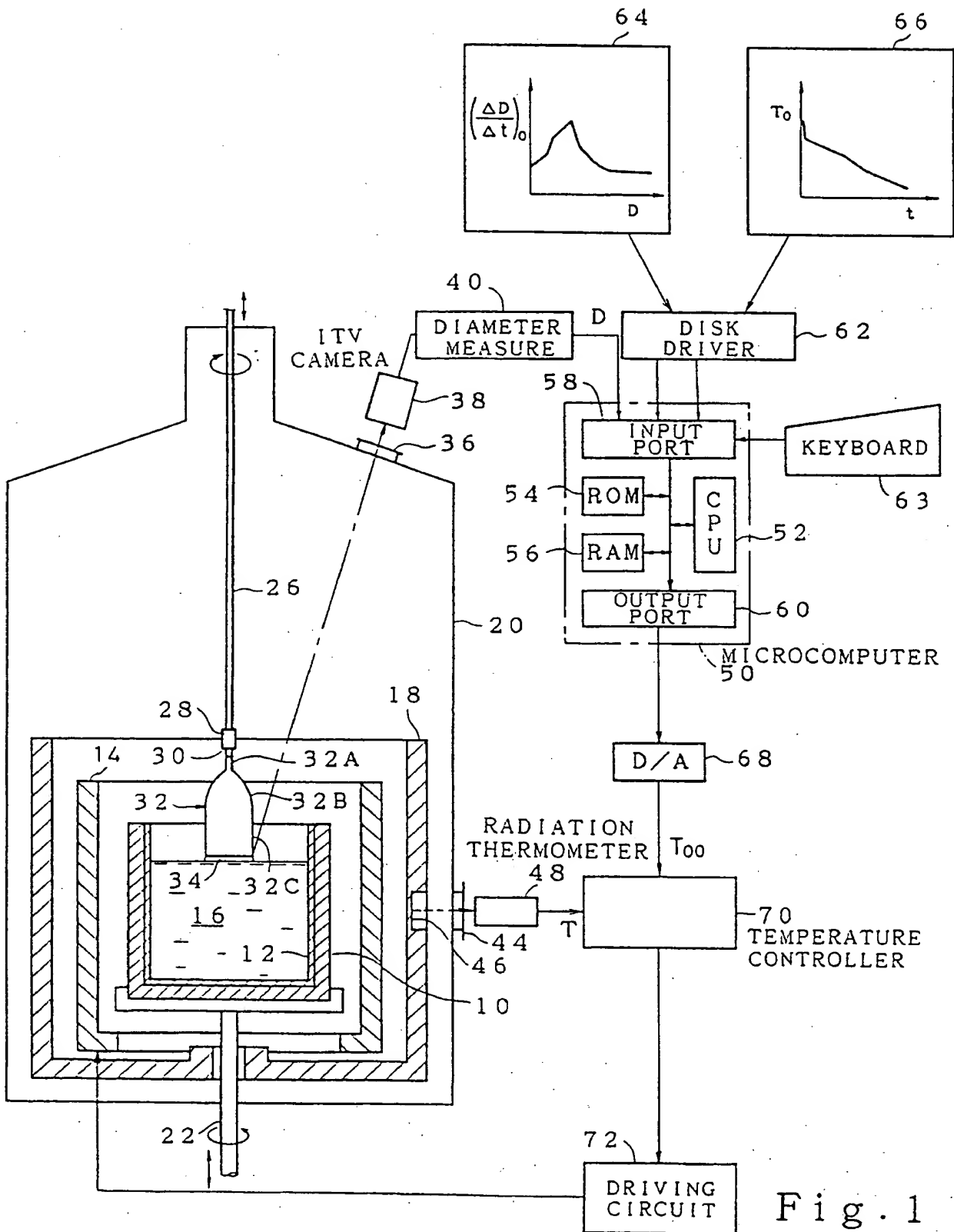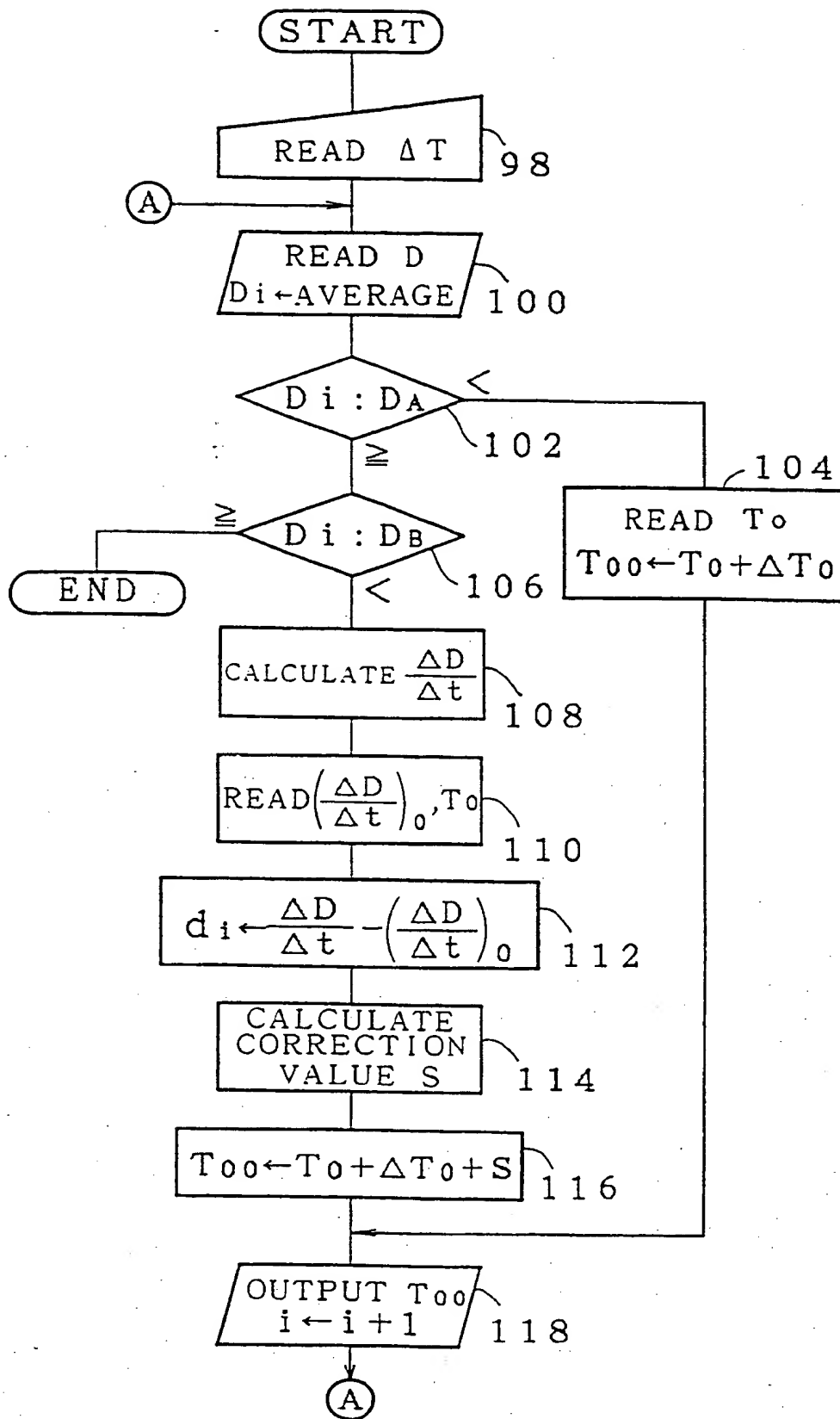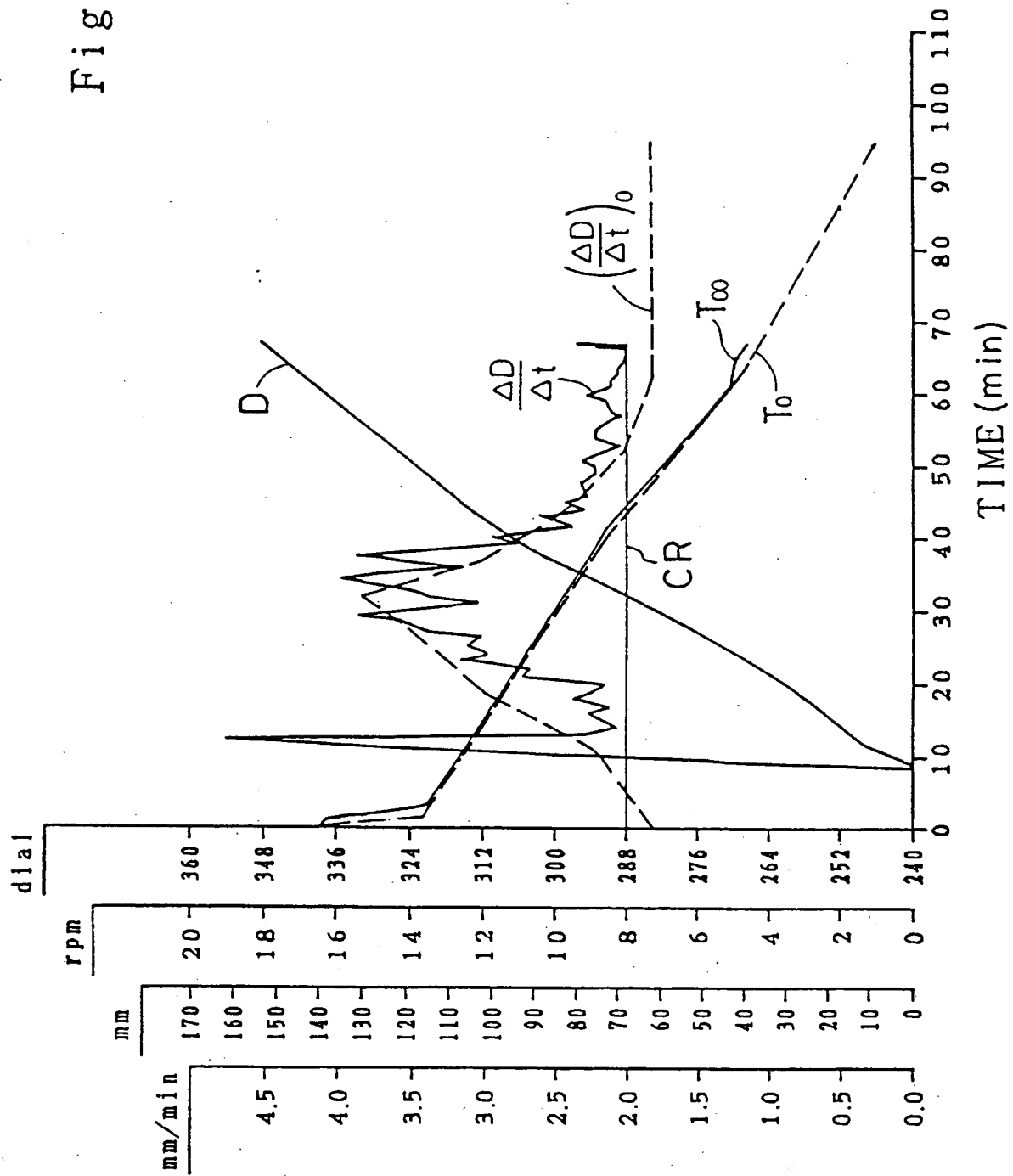
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Fig. 1

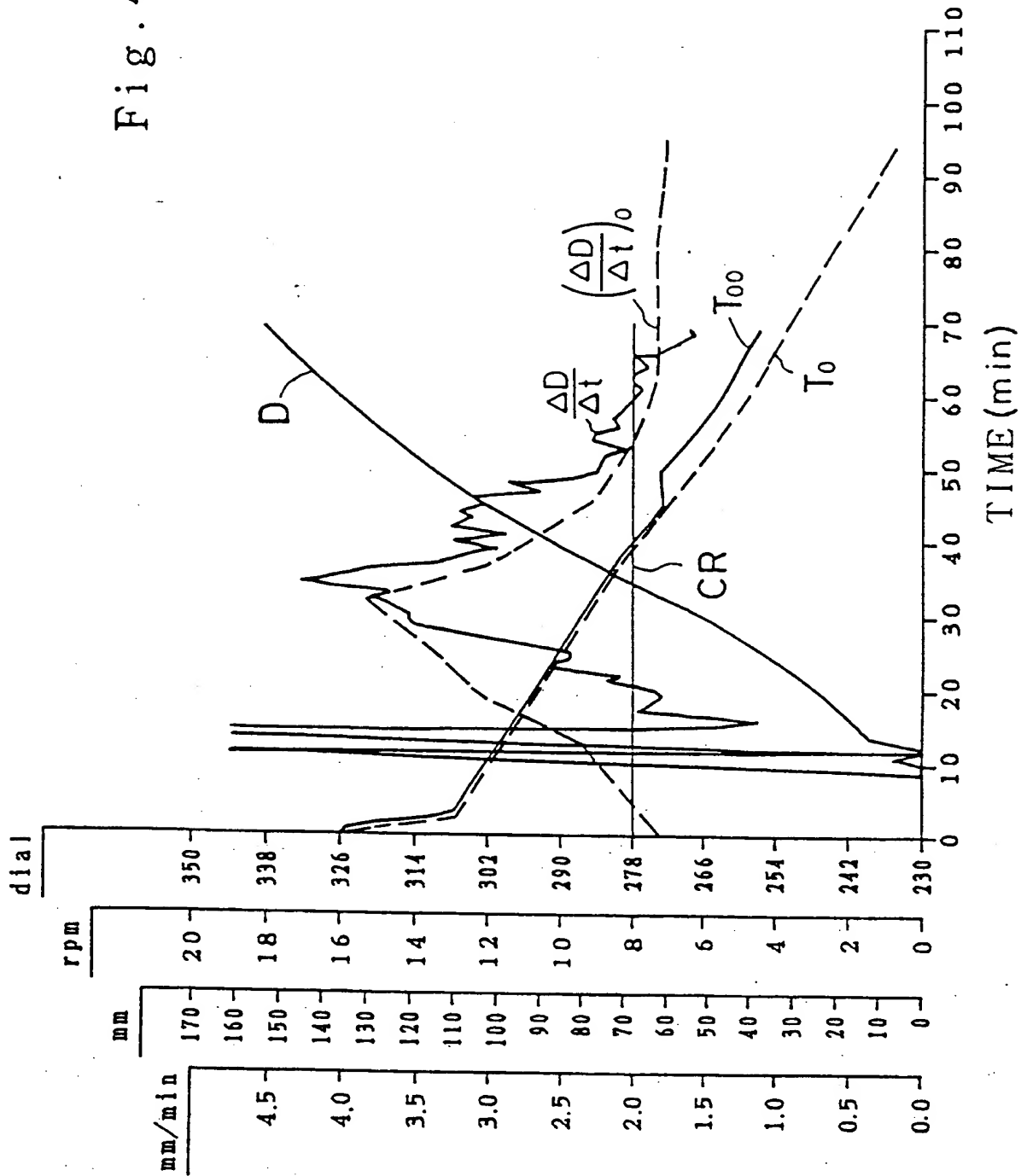START

READ ΔT 98

Ⓐ

READ D
$Di \leftarrow$ AVERAGE 100

$Di : DA$ 102 <

$Di : DB$ 106 <

$\geqq$ END

READ To
$Too \leftarrow To + \Delta To$ 104

CALCULATE $\dfrac{\Delta D}{\Delta t}$ 108

$READ\left(\dfrac{\Delta D}{\Delta t}\right)_0 , To$ 110

$d_i \leftarrow \dfrac{\Delta D}{\Delta t} - \left(\dfrac{\Delta D}{\Delta t}\right)_0$ 112

CALCULATE
CORRECTION
VALUE S 114

$Too \leftarrow To + \Delta To + S$ 116

OUTPUT Too
$i \leftarrow i + 1$ 118

Ⓐ

Fig.2

Fig.3

Fig.4

Fig.5

EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	EP-A-0 285 943 (SHIN-ETSU HANDOTAI CO.) * Column 4, lines 4-32; column 5, lines 6-41 *	1-3,6,8	C 30 B 15/22
P,X	EP-A-0 429 839 (SHIN-ETSU HANDOTAI CO.) * Claims 1-5 *	1-10	
A	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 19, no. 3, August 1976, pages 869-870, New York, US; E.M. HULL et al.: "Monitoring diameter of semiconductor crystals during automated growth"		
A	EP-A-0 294 311 (SHIN-ETSU HANDOTAI CO.)		
A	PATENT ABSTRACTS OF JAPAN, vol. 10, no. 23 (C-325)[2080], 29th January 1986; & JP-A-60 176 989 (TOSHIBA K.K.) 11-09-1985		
A	US-A-3 761 692 (COPE) * Column 2, lines 49-64 *	1,2,6	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
C 30 B

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	30 January 92	COOK S.D.